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THE EVALUATION OF UN-COOLED DETECTORS FOR LOW-COST THERMAL-IR EARTH OBSERVATION AT THE SURREY SPACE CENTRE

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ABSTRACT

In 2004, the four-micro-satellite Disaster Monitoring Constellation (DMC) became operational [1]. While the constellation currently utilizes visible and near-IR imagers, a candidate instrument for future DMC satellites is one operating in the thermal- IR. In this research programme, a prototype TIR imaging radiometer, compatible with the DMC imaging suite has been engineered. The 2.5 kg prototype instrument uses a 2-D commercial-off-the-shelf (COTS) un-cooled micro-bolometer array to collect data in any of several mid-wave and long-wave IR bands (3-5, 8-10, 10-12, and 8-14 μm). After characterizing the performance of the prototype, a computer model was created to predict its on-orbit performance. Analysis has shown that a flight version of this instrument would yield around a 0.5 K noise equivalent temperature difference (NETD) for a 300 K ground scene, a 300-metre ground sample distance (GSD), and a 185-kilometre ground swath. Its application in special niche, or currently ill-served mission areas, is proposed. One such application is autonomous global thermal change detection, dedicated to highly specialized user communities.

1. INTRODUCTION

Recently, Surrey Space Technology Limited (SSTL) fabricated and launched the last of four micro-satellites that currently make up the internationally owned Disaster Monitoring Constellation (DMC). DMC, now operational, is capable of providing medium resolution (32 m) Earth observation (EO) imagery of any location in the world within a 24-hour period. While the constellation currently utilizes imagers operating in the visible and near-IR wavebands, it will be possible to expand its capabilities by flying additional types of EO sensors as new micro-satellites are added or existing micro-satellites are replaced. One candidate for a next generation of DMC EO instrument is an imaging radiometer operating in the thermal-IR (TIR). In this research programme, the potential use of commercially available uncooled detector technology in the design of a functional DMC-compatible TIR imaging system was explored. Whether this detector technology can be adapted to a space-based EO application has been the prime focus of this programme.

2. METHODOLOGY

In the first phase of this study, a commercial-off-the-shelf (COTS) based prototype imager was designed, fabricated, and tested in the laboratory. The collected response and noise data, with the addition of an atmospheric model, was used to simulate the

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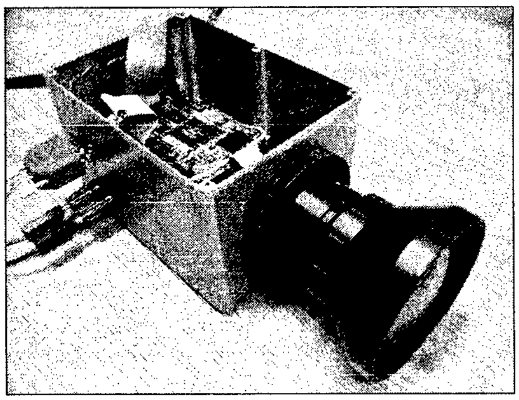
on-orbit performance. From the model, parameters were selected for a notional flight instrument concept and its application to niche mission areas was evaluated.

3. IMAGER PROTOTYPE

The 2.5 kg prototype instrument was assembled using a 2-D commercial-off-the-shelf (COTS) un-cooled micro-bolometer array and an f/1.25 100 mm focal length lens (see Figure 1). The 14-bit detector signal is read using capture hardware and imaging processing software common to other SSTL EO instruments. Instrument calibration was performed using two independent blackbodies.



Detector / Peltier Cooler Package:
- 240 x 320 uncooled microbolometer array
- Pixel Pitch: 45 μm; > 80 % fill factor
- Power Consumption: < 200 mW
- Mass: < 50 g

Optics:
- f/1.25, 100 mm focal length GASIR
- Mass: 0.625 kg
- Center MTF: 74% @ Nyquist freq.
- Corner MTF: 67.8 % @ Nyquist freq.

Electronics:
- 14 bit differential LVDS output
- Total noise: 480 μV

Figure 1: Prototype TIR imager used for ground test campaign

4. GROUND TESTING RESULTS

Bench-top testing consisted mainly of measuring the average pixel response for various blackbody temperatures and four candidate wavebands as well as the measurement of total system noise. From the data, it was possible to determine the effects of gain and offset, as well as validate the vendor provided responsivity across the wavebands of interest. Figure 2 shows two representative data sets with the left-hand plot simultaneously showing the measured and modelled pixel response.

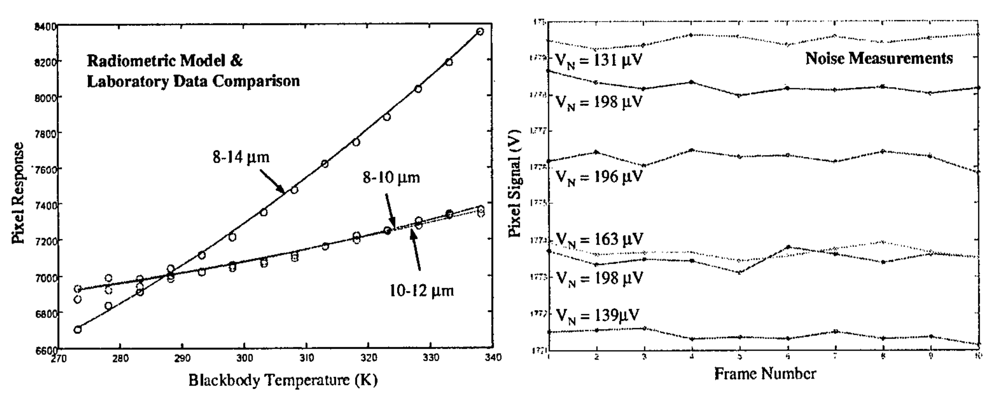


Figure 2: Blackbody response and rms noise data

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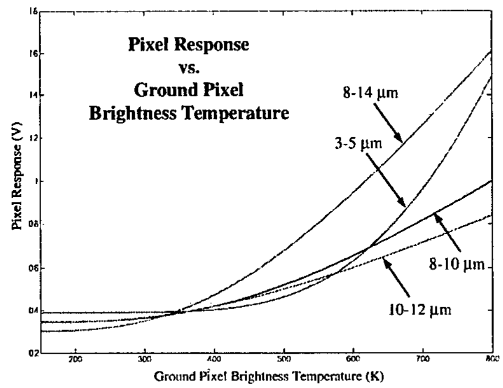
5. EXPECTED ON-ORBIT PERFORMANCE

After characterizing the response of the prototype, a computer model was created to predict its on-orbit performance. Simulations show that a flight version of this instrument under f/1.1 and the various atmospheric viewing conditions would yield noise equivalent temperature differences (NETDs) for the values shown below.



NETD @ 300 K Ground Pixel Brightness Temperature				
Atmospheric Model	**3-5 µm**	**8-10 µm**	**10-12 µm**	**8-14 µm**
No Atmosphere	4.34 K	0.72 K	0.84 K	0.31 K
Mid-Latitude Winter	9.37 K	1.05 K	0.91 K	0.43 K
Mid-Latitude Summer	13.32 K	1.35 K	1.27 K	0.58 K
Tropical	15.56 K	1.55 K	1.65 K	0.72 K

NETD @ 500 K Ground Pixel Brightness Temperature				
Atmospheric Model	**3-5 µm**	**8-10 µm**	**10-12 µm**	**8-14 µm**
No Atmosphere	0.17 K	0.22 K	0.33 K	0.01 K
Mid-Latitude Winter	0.36 K	0.31 K	0.38 K	0.15 K
Mid-Latitude Summer	0.46 K	0.41 K	0.53 K	0.20 K
Tropical	0.51 K	0.47 K	0.68 K	0.25 K

Figure 3: Expected on-orbit pixel response and NETDs

7. NOTIONAL FLIGHT INSTRUMENT CONCEPT

It is recommended that the laboratory testing be followed by further tests from an airborne platform and eventually from space. However, a notional design for the eventual 'operational' version of this instrument is shown in figure 4.

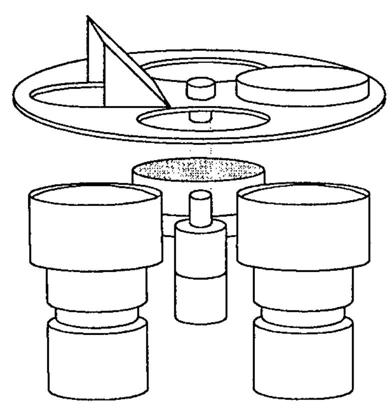


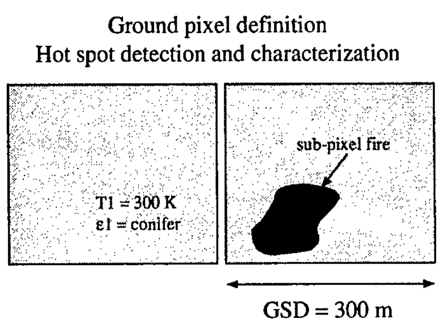
Figure 4: Flight instrument concept

The instrument consists of two micro-bolometer-based camera heads differing only in waveband. The two nadir-pointing cameras operate in push broom mode and utilize a 100 mm focal length, dual-band, f/1.1 moulded Gallium-Arsenide optic that can be easily tailored to collect EO data in any of several mid-wave and long-wave IR bands (3-5, 8-10, 10-12, and 8-14 µm). The instrument's custom-built electronics would permit easy integration of the instrument onto the DMC satellite bus, instrument command and control, and the down-linking of data.

Instrument calibration is performed via a turning wheel powered by an SSTL flight-tested drive motor. Two of the four apertures contain methods for performing a cold and hot body calibration. The first is a mirror angled at 45 degrees for viewing cold space and the other a blackbody surface which can be heated via a separate device located adjacent to the wheel.

6. POTENTIAL APPLICATIONS

Because this instrument yields a fairly course radiometric data set when compared to the current generation of large-scale TIR EO instruments, its application in special niche, or currently ill-served mission areas, has been proposed. One such application is autonomous hot spot detection, dedicated to highly specialized user communities. Figure 5 details the expected detection capabilities for various representative hot spot temperatures and two notional signal-to-noise ratio thresholds (10 and 100).



Sub-Pixel Hot Spot Temperature	3 - 5 μm SNR = 100		8 –14 μm SNR = 100	
	Pixel Fraction	Sub-Pixel Area (m2)	Pixel Fraction	Sub-Pixel Area (m2)
500 K	0.65	5,850	0.11	9,900
800 K	0.044	3,960	0.018	1,620
1200 K	0.009	810	0.005	450

Sub-Pixel Hot Spot Temperature	3 - 5 μm SNR = 10		8 –14 μm SNR = 10	
	Pixel Fraction	Sub-Pixel Area (m2)	Pixel Fraction	Sub-Pixel Area (m2)
500 K	0.065	585	0.011	990
800 K	0.0044	396	0.0018	1,62
1200 K	0.0009	81	0.0005	45

→ f/1.1; Mid-Latitude Summer MODTRAN Atmosphere

Figure 5: Minimum detectable sub-pixel hot spots

7. CONCLUSION

The approach taken in this study is valid for some space-borne Earth observation applications, especially when viewed in the extremely limiting environment of the DMC imaging platform. This approach is especially valid nn cases when it is not feasible to fly higher performing but larger and more power hungry cooled technology and there are user communities requiring highly specialized data sets within the capabilities of this instrument.

It is recommended that the latest available micro-bolometer arrays (640 x 480 and those specifically designed for 3-5 um) be evaluated for potential use. It is also recommended that the research described in this paper be continued with airborne and eventually space-borne demonstrations.

REFERENCE

1. da Silva Curiel, Alex, et. al., "First Results from the Disaster Monitoring Constellation (DMC)", presented at the 2003 IAF Congress, Bremen, Germany, paper IAA-B4-1302.